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Effects of Work Stress on Ambulatory Blood Pressure, Heart Rate, and Heart Rate Variability

Tanja G.M. Vrijkotte, Lorenz J.P. van Doornen, Eco J.C. de Geus

Abstract—Work stress has repeatedly been associated with an increased risk for cardiovascular disease. This study tested whether this relationship could be explained by exaggerated cardiovascular reactivity to work or impaired recovery in leisure time. Vagal tone was assessed as a possible determinant of these work stress effects. Participants included 109 male white-collar workers (age, 47.2 ± 5.3) who were monitored on 2 workdays and 1 nonworkday for ambulatory blood pressure, heart rate, and heart rate variability. Chronic work stress was defined according to Siegrist's model as (1) high imbalance, a combination of high effort and low reward at work, or (2) high overcommitment, an exhaustive work-related coping style indexing the inability to unwind. All findings were adjusted for possible differences in posture and physical activity between the work stress groups. High imbalance was associated with a higher heart rate during work and directly after work, a higher systolic blood pressure during work and leisure time, and a lower 24-hour vagal tone on all 3 measurement days. Overcommitment was not associated with an unfavorable ambulatory profile. Logistic regression analysis revealed that heart rate [odds ratio 1-SD increase 1.95 (95% CI, 1.02 to 3.77)] and vagal tone [odds ratio 1-SD decrease 2.67 (95% CI, 1.24 to 5.75)] were independently associated with incident mild hypertension. Surprisingly, the values during sleep were more predictive for mild hypertension than the values during work. The results from the present study suggest that the detrimental effects of work stress are partly mediated by increased heart rate reactivity to a stressful workday, an increase in systolic blood pressure level, and lower vagal tone. (*Hypertension*. 2000;35:880-886.)

Key Words: blood pressure monitoring, ambulatory ■ vagal tone ■ hypertension, detection and control
■ heart rate ■ hypertension, mild

High work stress has repeatedly been associated with increased risk for cardiovascular disease.¹⁻³ This association could derive in part from detrimental effects on blood pressure (BP) by recurrent autonomic nervous system reactivity to work-related stressors. Evidence for such work-stress effects comes from ambulatory BP studies, which show increased blood pressure levels in subjects with high work stress.⁴⁻⁶ Work stress in these studies was usually defined as job strain according to the model of Karasek and coworkers.⁷ Siegrist developed an alternative model for work stress to take into account the considerable individual variation in patterns of appraisal and coping in work-related situations.⁸ The Siegrist model uses 2 summary measures of work stress: imbalance, the ratio between extrinsic effort (demands on the job) and rewards (money, esteem, and status control), and overcommitment, a psychological coping style associated with the inability to withdraw from work obligations.⁸ The prospective evidence that these 2 work-stress components negatively affect cardiovascular health¹⁻³ is at least as strong as that reported for Karasek's job strain, but to date, no studies have looked at the effects of effort-reward imbalance and overcommitment or their interaction on ambulatory BP.

Increasing evidence shows that changes in vagal tone may be as important to stress-induced BP increases as sympathetic cardiac and vascular effects, for example, by contributing to a hyperkinetic circulation.⁹ The Framingham Heart Study¹⁰ has identified decreased vagal tone as an independent predictor of new-onset hypertension, which corroborated the importance of vagal tone in hypertension. Because of the prominent role of the parasympathetic system in recovery and restoration, we expect the work-stress effects on vagal tone to be more pronounced during the process of unwinding after work than during the actual work time. Indeed, in a prospective study, a 3-fold higher risk for coronary heart disease was found in subjects who reported that they could not relax after work.¹¹ Moreover, Siegrist and coworkers² found that high overcommitment scores independently predicted premature coronary events. This implies that subjects who scored high on effort-reward imbalance and overcommitment may be characterized by inadequate recovery after work rather than activation during the workday itself.

The present study examines the effects of effort-reward imbalance and overcommitment on ambulatory BP, heart rate

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(HR), and vagal tone in a group of middle-aged male white-collar workers. To allow a detailed assessment of the processes of recovery during the evening and sleep and restoration on a nonworkday, vagal tone in this study was monitored continuously on 2 workdays and 1 nonworkday. To expand on the previous studies on the association of vagal tone with hypertension, we will use these three 24-hour measurements to test whether vagal tone during periods of recovery and restoration predicts mild hypertension better than vagal tone during the workday.

Methods

Subjects

In 1995, 820 middle-aged (age, 35 to 55; 45.2 ± 5.3) white-collar workers, all working at the same large computer company and performing mainly sedentary work, received the effort-reward imbalance work stress questionnaire. Four hundred sixty subjects returned the questionnaire (response rate 57%), and from this group, 300 were willing to participate in ambulatory monitoring and blood sampling. From these, we selected 187 subjects (159 men and 28 women), who were in the upper and lower parts of the imbalance and overcommitment score distributions, by selecting only departments in which the variance in these scores was high. From these subjects, 63 were ineligible for the final study for different reasons (eg, moving or retirement, long-term illness, medication for hypertension, reported cardiovascular disease, and attrition during ambulatory monitoring). The remaining subjects participated in ambulatory cardiovascular monitoring between September 1996 and December 1997. The female population ($n=15$) was considered too small for gender specific statistical analyses and was therefore excluded. This left a total sample size of 109 male subjects for the present ambulatory study. The study protocol was approved by the Ethics Committee of the Vrije Universiteit, and all subjects gave written consent before entrance to the study.

Procedure

Participants underwent ambulatory monitoring on 3 days of the same workweek. They came to the health department of the computer company for the first monitoring on Monday morning between 8:00 AM and 11:00 AM. After instrumentation and explanation, the subjects went to their departments to follow their normal working routines. The next morning, 24 hours after the initial health department visit, the subjects returned and the monitors were removed. This procedure was repeated on Thursday morning. On Friday, the subjects took the ambulatory devices home for the 24-hour nonworkday registration. Thus, subjects were measured on 2 workdays, Monday and Thursday, and 1 nonworkday (Saturday or Sunday), always in that order.

During their ambulatory monitoring week, the subjects received questionnaires on personality and demographic information such as age, years of service, education level, and habitual physical activity. They also completed a second effort-reward imbalance questionnaire to obtain the work-stress scores that applied at the time of ambulatory monitoring. Body mass index was calculated as the weight in kilograms divided by the square of height in meters, and waist-to-hip ratio was calculated as the ratio between waist circumference and hip circumference.

Measures

Work Stress

A Dutch version of the Effort-Reward Imbalance questionnaire developed by Siegrist was used to measure perceived chronic work stress. This 47-item questionnaire has 3 main scales: extrinsic effort, reward, and overcommitment. Extrinsic effort refers to the demanding aspects of the work environment (subjective evaluation of the workload). Reward refers to esteem reward, monetary gratification, and status control. A score for imbalance was obtained by calculating

the ratio between extrinsic effort and reward. An individual's style of coping with work demands was assessed by a score on the overcommitment scale. This indicates a state of exhaustive coping that reflects frustrated but continued efforts and associated negative feelings. It consists of 4 factors: (1) need for approval, (2) competitiveness, (3) impatience and a disproportionate irritability, and (4) inability to withdraw from work obligations. Scores in the upper tertile (high overcommitment) indicate a critically high level associated with adverse health effects.¹² The low-overcommitment group comprised the lower 2 tertiles. Reliabilities (Cronbach α) for the overcommitment score, as well as for the score for the reward and extrinsic effort subscales, were 0.79, 0.75, and 0.66, respectively.

Ambulatory Measures

BP was recorded with a Spacelabs 90207 device at 30-minute intervals on the nondominant arm with an arm-cuff appropriate for the arm diameter. Subjects were instructed to remove the BP device when they went to bed and to attach the device again the next morning after they woke up. Therefore, BP was only measured during waking hours, not during sleep. HR and vagal tone were measured by the VU-AMS (version 4.6, TD-FPP, Vrije Universiteit, Amsterdam)¹³ continuously for a 24-hour period (daytime+sleep). Reliability and validity aspects and recording methodology of the VU-AMS have been described previously.¹⁴ Briefly, a continuous time series of R wave-to-R wave intervals were derived on line from a 3-lead ECG. Vagal tone was assessed by the root mean square of successive differences in these interbeat intervals (RMSSD), which has previously been proven to be a valid index of vagal tone¹⁵ and can be measured relatively easily on a 24-hour basis in large groups. To get an impression of the physical activity during the registration, the VU-AMS also monitors the amount of body movement (motility) of the subject by a vertical accelerometer. Average HR, RMSSD, and motility over 30-second periods were stored throughout the 24-hour recording time.

Diary Information

The VU-AMS produced an audible alarm approximately every 30 minutes (10 minutes randomized) to prompt the subjects to complete their activity diary. They were instructed to write down the time, activities, and body postures during the last 30-minute period in chronological order. The number of consumed cups of coffee, glasses of alcohol, and smoked cigarettes was also noted. In the evening, the subjects were asked to rate their mood over the past day by means of a shortened version of the Profile of Mood States.¹⁶ Profile of Mood States subscale scores on the depression-dejection, fatigue, anger-hostility, and tension-anxiety items were summed to yield a negative mood index. The sum of the vigor-activity and friendliness subscales were used to index positive mood.

Data Reduction and Analysis

Previous recommendations for excluding artifactual readings and outliers from ambulatory BP records were followed.¹⁷ Information on the type of activity and (changes in) posture from the diary was combined with the parameters from the VU-AMS with an interactive graphical program. Stationary fragments (same posture, same activity) were coded for posture (lying, sitting, standing, moving), activity (household activities, desk work, meeting, dinner, etc), day (Monday, Thursday, and nonworkday), and time of the day (work, leisure, and sleep). Mean values for HR and RMSSD for these coded fragments were calculated by the program and stored simultaneously with start and end times and the duration of the period. Each BP value from the Spacelabs device was similarly coded for posture, activity, day, and period of the day.

Multivariate ANOVA with the SPSS General Linear Models procedure was used to test for differences between the imbalance and overcommitment groups and for effects of period and effects of day. Potential covariates (age, waist-to-hip ratio, body mass index, waist circumference, cigarette smoking, alcohol consumption, education level, years of service, physical habitual activity, positive mood, and negative mood) were added to the multivariate ANOVA models if they showed a systematic correlation across days with the dependant

Work Stress and Personal Characteristics as a Function of Overcommitment Nested Under Imbalance

	Imbalance Low		Imbalance High		Total (n=109)
	Low (n=62)	High (n=24)	Low (n=13)	High (n=10)	
Overcommitment					
Imbalance	0.61±0.14	0.73±0.16	1.23±0.23	1.33±0.26	0.78±0.31
Overcommitment	8.26±2.73	15.75±2.77	10.90±0.73	16.2±3.58	10.98±4.40
Age, y	47.4±5.5	47.3±5.3	45.9±4.5	47.0±5.3	47.2±5.3
BMI, kg/m ²	25.2±2.5	24.9±3.6	25.5±2.8	27.1±3.9	25.4±3.0
WHR	0.92±0.07	0.90±0.08	0.87±0.10	0.90±0.06	0.91±0.08
Waist circumference, mm	925±84	921±115	911±127	942±96	924±97
Alcohol, glasses/week	15.4±11.5	13.8±13.1	17.8±13.0	14.2±11.0	15.4±11.9
Coffee, cups/day	5.2±2.5	4.8±2.4	5.6±1.9	4.7±2.6	5.2±2.4
Current smokers, %	27.4	20.8	30.7	30.0	26.6
Education level†	4.9±1.5	5.2±1.2	4.8±2.0	5.7±1.4	5.0±1.5
Habitual physical activity‡	1.4±1.1	1.5±1.2	1.2±1.2	1.8±1.1	1.4±1.1
Years of service, y	22.8±7.1	22.1±7.3	20.5±7.0	20.6±6.7	22.2±7.1
Positive mood§	17.7±4.5	17.0±3.8	16.6±3.8	15.9±3.5	17.2±4.2
Negative mood§	6.9±7.7	9.9±9.5	14.7±8.8	15.2±9.4*	9.3±8.9

BMI indicates body mass index; and WHR, waist-to-hip ratio.

*Significant difference between the high- and low-imbalance group ($P<.01$).

†Seven-point scale ranging from primary school to university level.

‡During your leisure time, how many times a week do you exercise until you sweat? Answers ranged from 0 (0 times a week) to 4 (≥ 4 times a week).

§Means of Monday, Thursday, and nonwork day.

variables. Significant interactions were analyzed post hoc by conducting pairwise comparisons. Bonferroni corrections for multiple comparisons protected against false significance.

Logistic regression models were used to examine whether mild hypertensive status, coded as yes/no, could be predicted from the ambulatory RMSSD and HR averaged over (1) all work, (2) all leisure time, and (3) all sleep periods, always after adjustment for covariates. Mild hypertensive status was defined as ambulatory diastolic BP (DBP) ≥ 85 mm Hg during work as well as leisure time. Results are summarized by the odds ratio (OR) and 95% confidence interval, with the OR expressed for a 1-SD decrease in RMSSD and 1-SD increase in HR. Work, leisure, and sleep time RMSSD were not normally distributed and, therefore, log transformed in the analyses.

Results

Subjects were divided into work stress groups on the basis of their scores for imbalance and overcommitment. Twenty-three subjects (21%) experienced a mismatch between high effort and low reward at the workplace. The other 86 subjects were classified as low imbalance. Overcommitment was dichotomized so that subjects in the upper tertile were considered high in overcommitment, and those in the other 2 tertiles were low in overcommitment. The Table shows that the group with the most stressful experiences at work comprised 10 subjects (9.2%) who reported high overcommitment and high imbalance. There were no interactions or main effects of imbalance and overcommitment on the confounding variables, except for negative mood. The high-imbalance group scored higher on negative mood ($P<0.01$) than the low-imbalance group.

The mean duration of the VU-AMS registrations on Monday, Thursday, and Friday was 22:24±1:32, 22:56±2:01, and 22:39±2:44 hours, respectively (16:00±2:30, 17:00±3:00, and 16:00±4:00 hours for BP, respectively). The average data loss of HR and RMSSD across the 3 measurement days was 14.0%;

14.1% of the BP recordings were invalid. No systematic relation existed between data loss and work-stress status.

The amount and type of physical activity during the measurements is an important factor that could account for differences in cardiovascular reactivity between the work-stress groups. Previous studies have shown that the variance in ambulatory signals because of physical activity can be captured largely by looking at posture.^{18,19} In our subjects, ambulatory HR, RMSSD, and BP were highly dependent on posture ($P<0.001$). A comparison of the time (number of minutes) spent in different postures showed that the 4 work-stress groups did not differ in the total duration of sitting, standing, walking, and lying (only during sleep) during the various periods of all 3 days (Figure 1). These results suggest that any ambulatory cardiovascular differences between the imbalance and overcommitment groups would not reflect different activity patterns during the ambulatory monitoring days. In fact, statistical analyses on (1) values during sitting-lying only and (2) all values, ie, regardless of posture, gave essentially the same results. Only the latter values will be presented.

Work Stress

Men classified as having high imbalance had significantly higher work and home systolic blood pressure (SBP) than men not having high imbalance (Figure 2). This difference for SBP was on average 3.9 mm Hg ($F=3.98$, $P=0.049$). No imbalance effect was found for DBP. Most notably, neither overcommitment nor the interaction of overcommitment with imbalance, had an effect on SBP and DBP.

As shown in Figure 2, the patterns of change for HR during the workdays and the nonworkday and between work, leisure, and sleep periods were different for the high- and low-

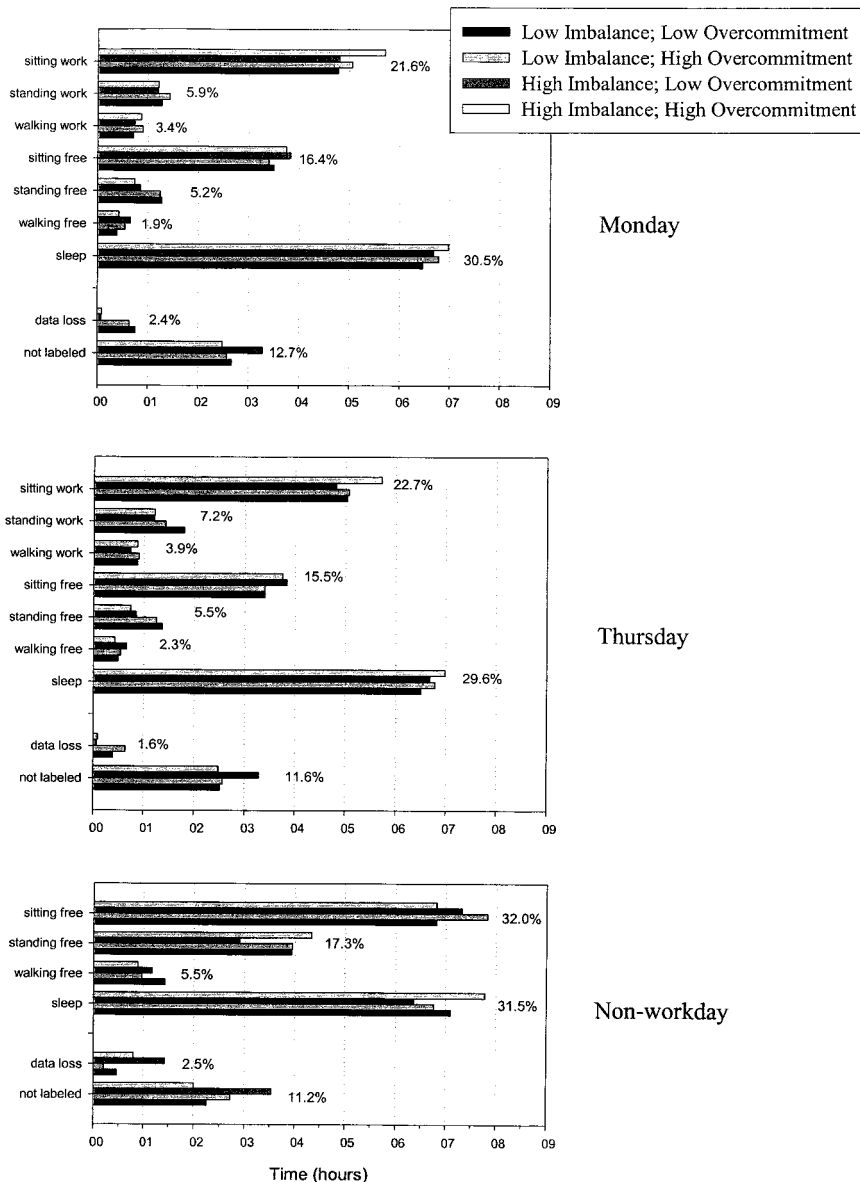


Figure 1. Amount of time spent in different postures during 2 workdays and 1 nonworkday as a function of imbalance and overcommitment.

imbalance groups (interaction effect $F=2.85$, $P=0.01$). Post hoc tests showed that during work and leisure periods on the days the subject went to work, the high-imbalance group had higher HRs compared with the low-imbalance group (6.8 bpm). These differences disappeared during sleep and indicated complete recovery of HR in the high-imbalance group. The data for RMSSD show a trend for the high-imbalance group to have lower RMSSD during all periods ($F=3.7$, $P=0.059$). Again, neither overcommitment nor the overcommitment by imbalance interaction was associated with HR or RMSSD in any of the periods.

RMSSD and Mild Hypertension

Of the 109 subjects, 30 subjects showed mean ambulatory DBP ≥ 85 mm Hg during work as well as leisure time and were classified as mild hypertensives. These mild hypertensives were equally distributed between the high- and low-imbalance groups (24 versus 6, respectively). A logistic regression model was fit (HL goodness of fit=4.57; df=8,

$P=0.802$), and it revealed that RMSSD was reduced and HR was increased in subjects with mild hypertension. The RMSSD values during sleep were by far the most predictive; including SBP reactivity (defined as SBP work–SBP leisure) and HR reactivity (HR work–HR sleep) into the model did not significantly improve the model. After adjustment for confounders (age, waist circumference, cigarette smoking, alcohol consumption, and physical habitual activity), 1-SD increase in mean HR during sleep corresponded with OR 1.95 (95% CI, 1.02 to 3.77) and 1-SD decrease in lnRMSSD corresponded with OR 2.67 (95% CI, 1.24 to 5.75). On the basis of this model, probabilities of mild hypertension as a function of nighttime RMSSD during sleep are displayed in Figure 3. There is a steep curvilinear relation between nighttime RMSSD and the incidence of mild hypertension.

Discussion

Work stress, defined as effort-reward imbalance, has repeatedly been shown to predict cardiovascular disease.^{1–3} The

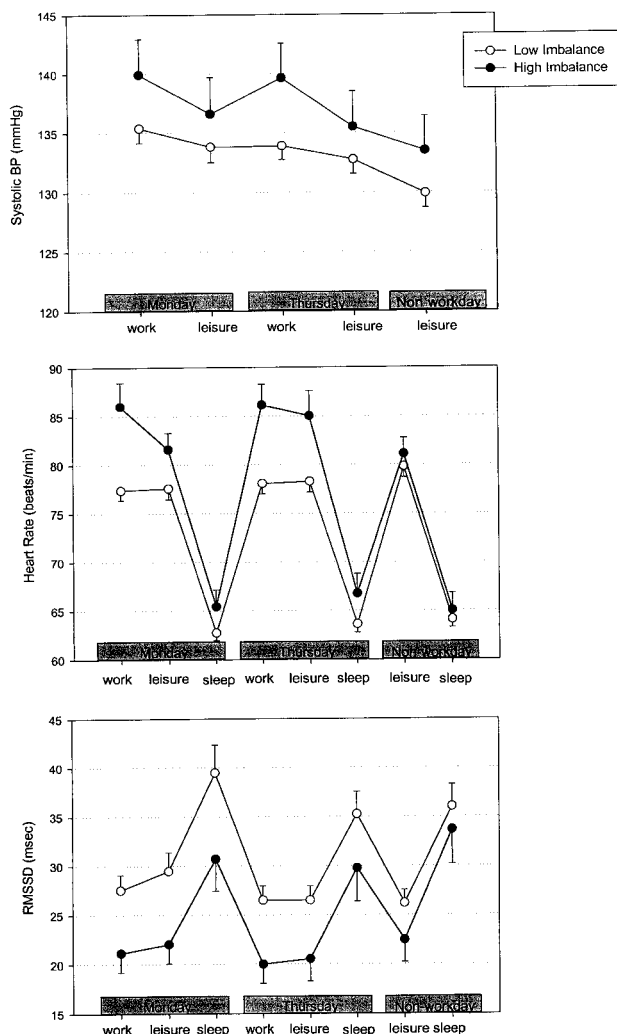


Figure 2. SBP, HR, and RMSSD (mean \pm SD) during work, leisure, and sleep (only HR and RMSSD) on 2 workdays and 1 nonworkday for the high- (●) and low-imbalance (○) groups.

results from the present study suggest that the detrimental effects of work stress are partly mediated through (1) increased HR reactivity to a stressful workday, (2) an increase in SBP, and (3) lower 24-hour vagal tone. These 3 characteristics of high-work stress are all associated with increased cardiac disease risk.^{20–22}

Work Stress and BP

An imbalance between extrinsic effort and reward at work (21% of the subjects) was associated with an average increase in SBP of 4 mm Hg. Similar to other ambulatory studies,^{5,6,18} we found a significantly higher SBP during work time compared with leisure time on the workdays and a higher average BP level during the workday compared with the nonworkday. However, the effects of imbalance were not specific to work time, ie, SBP was higher in the high-imbalance group even during leisure time and the nonworkday. Other studies provide additional data on sleep BP and show a work stress effect to be present even at night.^{5,6} Taken together, the current evidence shows that subjects with

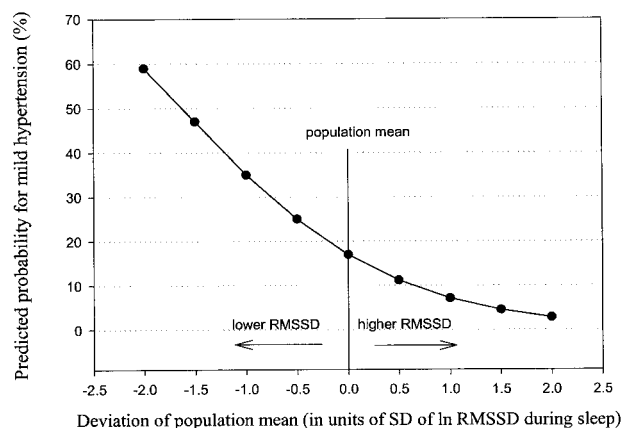


Figure 3. Probability of mild hypertension as a function of 0.5 SD change of natural-log transformed RMSSD during sleep. Plotted line is adjusted for the following covariates: HR during sleep, age, waist circumference, cigarette smoking, alcohol consumption, and habitual physical activity.

chronic work stress have increased 24-hour SBP levels that are not simply caused by increased BP during work time.

DBP was not found to be different in the high-work stress group, not even during work time. This finding has been reported before, but most of the previous studies did show DBP effects, although always less pronounced than SBP effects.^{4–6} Most studies, however, used participants from different occupations. This increases variation in social class and work-related physical activity patterns. The present study had a homogenous population of sedentary white-collar men in whom work-stress effects were not amplified by social class or physical activity.

Work Stress, HR Reactivity, and Vagal Tone

HR and HR reactivity are independent risk factors for cardiac disease.^{20,21} The few studies that reported on ambulatory HR in relation to work stress²³ found higher HRs (on average 4 bpm) in the high-work stress groups. In the present study, the most striking difference between the high- and low-imbalance groups was a selective increase in HR during work and leisure time after work. No difference in HR was found during sleep and during the nonworkday. This pattern of results is in contrast to our expectations that work stress would mainly affect recovery and restoration. These expectations were based on a number of recent findings that suggested recovery from stress may be as important to disease as reactivity during stress.^{2,11,24} Some evidence existed for slow recovery in subjects with high effort-reward imbalances, who had higher HRs during leisure time. However, these HR effects of work stress were not present during the night and did not carry over to the nonworkday. Most notably, we failed to find significant effects of overcommitment on any of the measured cardiovascular variables. Because overcommitment is characterized by worrying and the inability to withdraw from work obligations, this scale should have showed the largest sensitivity to individual differences in recovery.

As the underlying cause for stress-related HR reactivity, hyperactivity of the sympathetic nervous system is often evoked as a main explanation. The present study provides evidence that, in a natural setting, high HR reactivity of chronically stressed subjects is also associated with low vagal tone. At first sight it seems surprising that vagal tone was lower in all periods, ie, at night and during the nonworkday, whereas HR in the high work stress subjects was higher selectively during the workdays. A simple explanation for this discrepancy may be that, in view of the observed large standard deviations for RMSSD, our study lacked the statistical power to detect a significant group-by-period interaction for vagal tone. Inspection of Figure 2 suggests that a large sample size might have shown that on the nonworkday, the work-stress groups become more similar for vagal tone. Alternatively, a chronically low vagal tone may be precisely the predisposition that is hinted at in stress-diathesis models in cardiovascular disease.^{25–27} According to the stress-diathesis model, (genetic) susceptibility to hyperactivity, as well as actual exposure to adequate psychosocial triggers, exerts a synergistic effect on disease risk. It is conceivable that subjects with a predisposition for low vagal tone (an imperfect vagal brake²⁸) show the largest HR reactivity, specifically when there is increased cardiac sympathetic drive, for example, during a stressful work situation.

Lower vagal tone and higher HR have been found in patients with borderline hypertension,⁹ and prospective studies suggest that higher HR and lower vagal tone actually precede future hypertension.¹⁰ The results from the logistic regression analysis are in clear support of the importance of vagal tone and HR level for BP. However, HR and BP reactivity to stress at work were not associated with mild hypertensive status or with overall BP level. This applied to the entire group as well as the subset of high work stress subjects. Instead, HR and RMSSD during sleep appeared to be the best predictors of mild hypertension. Our results are in accordance with the idea of an overall hyperkinetic circulation in borderline hypertension.⁹

Causality

In summary, our results are parsimoniously described by an association of high work stress and low vagal tone. Secondary findings of high HR reactivity as well as high BP could be largely ascribed to low vagal tone as outlined above. However, this leaves the main question of causality for the association of work stress and vagal tone. It is possible that chronic stress directly reduces vagal tone through an unknown neurophysiological mechanism. This may sound unsatisfactory, but it must be pointed out that no mechanism has been described to account for the well-known and significant decrease in vagal tone with age. Perhaps chronic stress speeds up this normal autonomic nervous system ageing process of vagal tone. Alternatively, an unfavorable psychological profile may underlie both work stress and vagal tone. Low vagal tone has been found to be characteristic of an anxious-depressive²⁹ or a hostile³⁰ personality. In our subjects, the mood questionnaire showed that subjects who scored high on imbalance also scored high on negative mood (depression, anxiety, and anger). It is unclear to what extent an unfavor-

able psychological profile precedes work stress or whether an unfavorable psychological profile is a consequence of it. Thus, the causality of the association between self-reported work stress and the unfavorable ambulatory profile found in our subjects remains to be established.

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